Appendix 6-D

(updated January 2004)

MDOT Guidelines for Evaluation of Scour and Scour Analysis Worksheets

Rev: September 13, 2002

MICHIGAN DEPARTMENT OF TRANSPORTATION

GUIDELINES FOR EVALUATION OF SCOUR AT EXISTING STRUCTURES

INTRODUCTION

These guidelines are proposed for the evaluation of scour at existing bridge structures for the Michigan Department of Transportation (MDOT) and local agencies. The guidelines supplement the following Federal Highway Administration (FHWA) publications and directives on scour:

1. "Evaluating Scour at Bridges," HEC -18 (Fourth Edition)

2. Technical Advisory T 5140.23

3. "Stream Stability at Highway Structures," HEC - 20 (Third Edition)

Scour is a dynamic sediment transport process. Research on scour is ongoing, and revisions to the methods of scour and stream stability analyses may occur.

These guidelines are organized to discuss the priority of evaluation, the three levels of analysis, the National Bridge Inventory System (NBIS), the plan of action, and design of scour countermeasures for scour critical bridges. It is important that an interdisciplinary team consisting of hydraulic, geotechnical, and structural engineers be involved in all levels of analysis and the evaluation process.

Chapter 10 of FHWA's HEC-18 outlines a scour evaluation process for existing bridges. HEC-18 recommends documentation of each level of analysis. Documentation for Michigan includes updating Item 113 of the NBIS at each level of analysis and action and retaining the Level One and Level Two Worksheets. The Level Two Worksheet should include, if needed, recommended scour countermeasures and a "Plan of Action." The Plan of Action should include a timetable to implement the design and construction of accepted scour countermeasures.

PRIORITY OF EVALUATION

In 1991, MDOT developed a scour screening procedure for development of an initial priority list. This procedure was approved by FHWA and distributed to local agencies. Each agency should now have a "priority list" based on this procedure to start its scour evaluation program. An agency should use this priority list to schedule the proposed Level One analysis given in these guidelines. The Level One analysis must be completed to determine the need for a Level Two analysis.

Structures with unknown foundations will have Item 113 coded as a "U" in the NBIS. MDOT recommends as a minimum a Level One analysis, and the hydrologic, hydraulic, and scour calculations of a Level Two analysis be done. The findings can be used to evaluate the potential risk to these structures once the type of foundation is determined.

LEVEL ONE - QUALITATIVE ANALYSIS

A Level One analysis is an information gathering effort consisting of office and field reviews of the structure. The following information should be obtained, reviewed, and commented on:

- Bridge Inspection Reports
- Underwater Inspection Reports (if available)
- Items 60, 61, 71, 92, 93, and 113 of the NBIS (see HEC-18, Appendix J, for definitions)
- Construction, design, and maintenance files for repair and maintenance work done on the structure
- Hydraulic Data (Flood Insurance Study or original design analysis)

The Level One analysis procedure is outlined in Chapter 3 of HEC-20. It is a six-step process that covers stream characteristics, land use, stream stability, lateral stability, vertical stream stability, and channel response to change. Items used in the initial screening procedure should be verified, corrections made to the screening database, and the priority list updated accordingly.

A field investigation will be required to obtain the above stream characteristics and confirm the minimum hydraulic parameters, i.e., channel slope, channel and overbank roughness coefficients, plan elevations and dimension of structure, foundation conditions, etc.

If a Level Two analysis is recommended, a code of "6" should be entered for Item 113.

LEVEL TWO - BASIC ENGINEERING ANALYSIS

The Level Two scour analysis is an eight-step process to define stream stability and scour problems. These steps cover:

1. Hydrology or flood history
2. Hydraulic conditions
3. Geotechnical - bed and bank material evaluation
4. Watershed sediment yield
5. Incipient motion analysis
6. Armoring potential
7. Rating curve shifts
8. Scour conditions

Appendix B of these guidelines provides a worksheet for a Level Two scour analysis. The following is a discussion of each of these eight steps:

HYDROLOGY

The discharge estimate used in the scour screening procedure should not be used for scour design. The Michigan Department of Environmental Quality (MDEQ) will not provide flood frequency discharge estimates for scour evaluation studies. Therefore, it is recommended that a range of flood discharges that approximate the 2 percent, 1 percent, and 0.2 percent chance floods be used. If flood estimates are not readily available, the MDEQ recommends the following methods for estimating flood discharges:

- For drainage areas less than 20 square miles use:

  "Computing Flood Discharges for Small Ungaged Watersheds," by Rick Sorrell, P.E., Michigan Department of Environmental Quality, October 2001.

- For drainage areas greater than twenty square miles use:

  "DNR/USGS Peak Flow Regression," by Hope Meyers Croskey, Engineering-Water Management Division, Michigan Department of Natural Resources, February 1985. The accompanying report is "Statistical Models for Estimating Flow Characteristics of Michigan Streams," U.S. Geological Survey, Water-Resources Investigations Report 84-4207.

- Drainage area ratio method on gaged streams can be used where USGS gages exist, or recent MDEQ discharge estimates at or near the bridge may be used. The ratio of the drainage areas should be raised to the 0.89 power when estimating the discharge. This method should only be used if the hydrologic characteristics of the two drainage basins are similar.

Estimated discharges are for evaluation purposes only. Design and construction of structure repair, replacement, or scour countermeasures requires a discharge estimate from MDEQ with a permit application for the proposed work. The MDEQ discharge estimate should be compared with the range of discharges used in the scour evaluation. Engineering judgement should be used to determine if the scour evaluation is adequate.

NOTE: The use of a flood hydrograph is beneficial to scour analysis since it can illustrate the time and duration that hydraulic forces are present to transport bed material. However, development of flood hydrographs for the recommended range of flood flows is beyond the scope of a Level Two analysis and is recommended for Level Three.

HYDRAULICS

Chapter 2 of HEC-18 recommends the utilization of existing hydraulic studies. If these studies are not available, a "worst-case analysis" is suggested. It is assumed that a detailed hydraulic survey of the channel cross sections will not be done. Channel cross sections can be developed based on existing bridge plans, topographic maps, and data gathered during the Level One field investigation. These cross sections should have a minimum of eight station points to define the cross section. A sufficient number of cross sections downstream of the structure should be input to achieve a normal water surface. Duplication of existing cross sections is an acceptable technique.

MDOT recommends the use of the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-RAS computer program for the computation of water surface profiles and the hydraulic parameters needed in the scour calculations.

GEOTECHNICAL

A soil gradation curve of streambed and overbank material is needed to determine the D_{50} and D_{84} particle sizes for use in the respective contraction scour and pier scour equations. Gradation curves or soil boring information used in the original plans of the structure can be used. A geotechnical engineer should be consulted for an estimation of the D_{50} and D_{84}.

If existing plans or soil information are not available, analyze based on the worst-case scenario. It is recommended that Laursen's live bed contraction scour equation be used with a K_1=0.69.

WATERSHED SEDIMENT YIELDS

The availability of watershed yield is imprecise. Information on Michigan streams is limited and, therefore, not used in the overall evaluation of a Level Two Analysis.

INCIPIENT MOTION ANALYSIS

Use of the Shields relation (Chapter 6 of HEC-20) for the range of discharges may provide information on the channel stability and what flood may cause stream channel instability. This relation is recommended for gravel or cobble stream systems only.

ARMORING POTENTIAL

Determination of the potential armoring of a streambed is discussed in Chapter 6 of HEC-20.

RATING CURVE SHIFTS

USGS stream gage data is limited to a few locations on Michigan streams. Analyses of rating curve shifts have not been completed in Michigan. Therefore, this portion of a Level Two analysis cannot be done.

SCOUR CALCULATIONS

Scour has three additive components: local scour at abutments and piers, contraction scour, and aggradation/degradation of the streambed. HEC-18 provides detailed computational procedures. The total scour depth should be reviewed by geotechnical and structural engineers to evaluate the stability of the structure.

LEVEL THREE - MATHEMATICAL AND PHYSICAL MODEL STUDIES

A detailed evaluation and assessment of stream stability can be completed by either mathematical or physical model studies. However, such studies are beyond the scope and monies available for a majority of Michigan projects.

NATIONAL BRIDGE INVENTORY SYSTEM (NBIS)

The scour evaluation program should result in the proper code for Item 113 of the NBIS. For state trunkline structures, the worksheet with the appropriate code should be forwarded to the Hydraulics/Hydrology Unit for review after each level of analysis. A copy of the Structure Inventory and Appraisal (SI&A) form (MDOT form Q1717A) will then be forwarded to the Bridge Operations Unit of MDOT. Local Agencies should send the SI&A form to the Bridge Operations Unit, Construction and Technology Division, Michigan Department of Transportation, P.O. Box 30049, Lansing, Michigan, 48909. Local agencies may also submit the form electronically.

PLAN OF ACTION AND SCOUR COUNTERMEASURES

Scour countermeasures are needed at the bridge to make it less vulnerable to either damage or failure from scour. For existing bridges, recommended countermeasures include:

- Riprap at piers and abutments with monitoring (visual, cross sections, instrumentation, etc.) during and after flood events
- Guide banks
- Channel improvements
- Strengthening bridge foundations
- Relief bridges

A plan of action is needed and can be part of the Level Two documentation. The plan of action should be developed among the hydraulic, geotechnical, and structural engineers. Examples include the following:

- Monitor for scour during regular bridge inspection
- Increase monitoring frequency
- Temporary countermeasures - riprap and monitor
- Selection of scour countermeasures
- Scheduling of scour countermeasure construction

LEVEL ONE WORKSHEET

Revised 5/06/02

MICHIGAN DEPARTMENT OF TRANSPORTATION
LEVEL ONE SCOUR ANALYSIS WORKSHEET

Date:_________ By:____________ Structure No:_____ Control Section:_________

Job No._________ Route:____________ Watercourse:_______________________

All references are to HEC-20, 3rd Edition.

Data Collection

____ Plans
____ Bridge Inspection Reports (Maintenance Division)
____ Underwater Inspection Reports (Maintenance Division)
____ Review existing items 60, 61, 71, 92, 93, and 113 of the NBIS
____ Review available construction, design, and maintenance files for repair and maintenance work done on structure

Field Investigation Date:____________

____ Channel bottom width approximately one bridge span upstream = ________ feet

____ Overbank and channel Manning's roughness coefficients

__________ Left ___________ Channel __________ Right

____ Is there sufficient riprap? Abutments __________ Piers ___________

____ Photographs

____ Cross sections at upstream and downstream faces of bridge

Comments:

Stream Characteristics

___ Complete the attached Figure 2.6 from HEC-20.

Comments:

Land Use: Identify the existing and past land use of the upstream watershed:

Urban Area Yes__ No__ Comments:
Sand and Gravel Mining Yes__ No__ Comments:
Undeveloped Land Yes__ No__ Comments:

Lateral Stability: Refer to HEC-20, Section 2.3.9 on Channel Boundaries and Vegetation for channel bank stability. Comment:

Vertical Stability:

- streambed elevation change from as-built plans? Yes _____ No _____

- exposed pier footings (degradation)? Yes _____ No _____

- exposed abutment footings (degradation)? Yes _____ No _____

- channel bank caving in (degradation)? Yes _____ No _____

- eroding floodplain (aggradation)? Yes _____ No _____

- crossing at confluence or tributaries? Yes _____ No _____

- bridge sites upstream and downstream? Yes _____ No _____

- grade or hydraulic controls, i.e. dams, weirs, diversions? Yes _____ No _____

- foundation on rock Yes _____ No _____

- channel armoring potential Yes _____ No _____

Comments:

Stream Stability: Make a qualitative assessment of the overall stream stability by referring to the above information and Figure 2.6 and Table 3.2 from HEC-20 (attach copies of figures).

Stable_____ Unstable_____ Degrading _____ Aggrading _____

Comments:

RECOMMENDED NBIS ITEM 113 CODE:_____

LEVEL TWO ANALYSIS NEEDED: YES___ **NO**___

Worksheet approved by:___________________ P.E. License # ________ Date ________

LEVEL TWO WORKSHEET

Revised: 5/06/02

MICHIGAN DEPARTMENT OF TRANSPORTATION
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Date:_____________ By:______________________

Structure No:_____ Control Section:___________ Job No.___________

Route:____________ Watercourse:____________________________

Page numbers refer to HEC-20, 3rd Edition and HEC-18, 4th Edition. Attach water surface profile modeling printouts with pertinent variables highlighted. Scour calculations automatically done by HEC-RAS are not acceptable. All calculations must be attached or on the back of their respective pages.

1. **Hydrology:**

   Method of Analysis: DEQ estimate, SCS, Regression, DAR to gage, other

   Drainage Area:________ square miles

   Q_{50} = _________ cfs Q_{100} = _________ cfs Q_{500} = ___________ cfs

2. **Hydraulics:** Water surface profiles by: HEC-2 ___ WSPRO ___ HEC-RAS___

3. **Geotechnical:** Bed and overbank material values:

   D_{50} ____ D_{84} ___ (ft) Left Overbank

   D_{50} ____ D_{84} ___ (ft) Right Overbank

   D_{50} ____ D_{84} ___ (ft) Main Channel

   Source of information:

4. **Incipient motion analysis:** For gravel and cobble streams only. Refer to Page 6.14 of HEC-20.

5. **Armoring potential:** Refer to Page 6.16 of HEC-20.

LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. ____ C.S.___________ Job No._________ By:______________ Date:________

6. **Scour calculations**

LONG-TERM BED ELEVATION CHANGES - AGGRADATION/DEGRADATION

___ Use information from **Level One** Analysis

___ Use information from bridge inspection reports

___ Estimate change during the next 100 years if enough information exists

Estimated aggradation/degradation = _____ feet

*** Do not adjust fixed bed hydraulics for contraction scour and local scour. If channel has aggraded, do not adjust the estimated scour depth.

CONTRACTION SCOUR (Section 5.2, HEC-18)

Bridge Site Condition:

CASE: 1a__ 1b__ 1c__ 2__ 3__ 4__

Compare critical velocity V_c to the mean velocity V.

$V_c = 11.17\ y^{1/6}\ D^{1/3}$ (p. 5.2, HEC-18)

y =

D_{50} =

V_c =

If $V_c < V$, use Laursen's Live-Bed contraction scour.

If $V_c > V$, use Laursen's Clear-Water contraction scour.

If coarse sediments in bed material, see p 5.12, HEC-18.

LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. ____ C.S.___________ Job No._________ By:____________ Date:_________

Laursen's live-bed scour equation (p 5.10, HEC-18):

$y_2/y_1 = (Q_2/Q_1)^{6/7}(W_1/W_2)^{k_1}$ and

$y_s = y_2 - y_0$ = average contraction scour depth (feet)

y_1	=	___________ ft	V^*	=	___________ ft/s
y_2	=	___________ ft	ω	=	___________ ft/s
y_0	=	___________ ft	S_1	=	___________ ft/ft
W_1	=	___________ ft	V^*/ω	=	___________
W_2	=	___________ ft	k_1	=	___________
Q_1	=	___________ cfs	y_s	=	___________ ft
Q_2	=	___________ cfs			

Laursen's Clear-Water Contraction Scour (p. 5.12, HEC-18)

$y_2 = (0.0077\ Q^2\ /(D_m^{2/3}\ W^2\ ))^{3/7}$

$y_s = y_2 - y_0$ = average scour depth (feet)

y_0	=	___________ ft	D_m	=	___________ ft
y_2	=	___________ ft	D_{50}	=	___________ ft
Q	=	___________ cfs	y_s	=	___________ ft
W	=	___________ ft			

LOCAL SCOUR

ABUTMENTS

Froehlich's live-bed scour equation. (If $L'/y_1 > 25$, use HIRE equation, p. 7.8, HEC-18.)

Froehlich's equation : $y_s / y_a = 2.27\ K_1\ K_2\ (L'/y_a)^{.43}\ (Fr)^{0.61} + 1$ (p. 7.8, HEC-18)

LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. ____ C.S. ____________ Job No.__________ By:______________ Date:________

		Left Abutment	**Right Abutment**
K_1	=	___________	___________
K_2	=	___________	___________
L'	=	___________ ft	___________ ft
A_e	=	___________ ft^2	___________ ft^2
Q_e	=	___________ cfs	___________ cfs
V_e	=	___________ ft/s	___________ ft/s
Fr	=	___________	___________
y_a	=	___________ ft	___________ ft
y_s	=	___________ ft	___________ ft

PIER(S)

Colorado State University equation (p. 6.2, HEC-18):

$$y_s/y_1=2.0\ K_1\ K_2\ K_3\ K_4\ (a/y_1)^{0.65}(Fr_1)^{0.43}$$

Pier #:		___________	___________	___________
y_1	=	___________ ft	___________ ft	___________ ft
K_1	=	___________	___________	___________
K_2	=	___________	___________	___________
K_3	=	1.1	1.1	1.1
K_4	=	___________	___________	___________
a	=	___________ ft	___________ ft	___________ ft
V_1	=	___________ ft/s	___________ ft/s	___________ ft/s
Fr_1	=	___________	___________	___________
y_s	=	___________ ft	___________ ft	___________ ft

Note: If there is a possibility of channel migration, use the worst-case condition for all piers. For complex pier foundations, see Section 6.4, HEC-18.

SUMMARY

LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. ____ C.S.___________ Job No._________ By:____________ Date:_________

100 YEAR

Element	Long-term (ft)	Contraction (ft)	Local (ft)	Total (ft)
Left Abutment				
Right Abutment				
Pier #				
Pier #				
Pier #				

Adjust total scour depth as needed if scour holes overlap.

500 YEAR

Element	Long-term (ft)	Contraction (ft)	Local (ft)	Total (ft)
Left Abutment				
Right Abutment				
Pier #				
Pier #				
Pier #				

____ Attach sketch or marked copy of existing design plan showing 100-year and 500-year total scour depths in relation to foundation. Foundation elevations must be shown.

Geotechnical Evaluation of scour results by: _________________

Structural Evaluation of scour results by: ___________________

Is the structure stable under the estimated scour depth presented in this scour evaluation?

Yes ___ No ____

RECOMMENDED NBIS ITEM 113 CODE: ____ (p. J.14, HEC-18)

LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. ____ C.S. __________ Job No._________ By:____________ Date:_________

ATTACHMENTS:

1. Calculations
2. Water surface profile computer output with pertinent values highlighted
3. Sketch of bridge with scour depths in relation to foundation
4. Scour countermeasure calculations with plans showing limits of countermeasures
5. Recommended plan of action

Worksheet approved by:_________________ Date:___________________

P.E. LICENSE # ____________

Additional comments: